IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR UNITED STATES LETTERS PATENT

Title: Window that Generates Solar-powered Electricity

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Field of the Invention

The present invention relates to the field of solar generated electricity.

Background of the Invention

The traditional uses of panels of solar cells have not realized their full potential because the electricity produced by these panels of solar cells is more expensive than that generated by the consumption of fossil fuels.

Glass panes are a very common exterior feature of high-rise office and apartment buildings. Sometimes these high-rise buildings are called skyscrapers. Glass panes afford views for the workers and occupants in the high-rise buildings. Additionally, glass panes permit sunlight to enter the building, to illuminate its interior.

Via pivot shafts, gears, and pinions, this invention uses solar cells between the glass panes of double-pane windows to produce solar generated electricity while generally allowing a portion of the views afforded by glass panes themselves. These electricity-producing double-pane windows could be used in any structure, such as a home or trailer, as well as a high-rise building. However, these electricity-producing

double-pane windows are particularly advantageous to high-rise buildings where there is so much glass in use.

Summary of the Invention

The object of the present invention is to provide a sealed double-pane window that also serves as a power source because the double-pane window houses a plurality of solar cells. More specifically, this invention uses pivot shafts to direct narrow strips of solar cells to track the apparent motion of the sun. When the sun has past the window, or before the sun has approached the window, the solar cells are placed in a parked position which is preferably perpendicular to the glass, to maximize the view afforded to the office worker. Thus, the viewer merely sees the thin dimension of each solar cell when electricity cannot be generated.

Further objects and advantages of the invention will become apparent as the following description proceeds and the features of novelty which characterize this invention are pointed out with particularity in the claims annexed to and forming a part of this specification.

Brief Description of the Drawings

The novel features that are considered characteristic of the invention are set forth with particularity in the appended claims. The invention itself; however, both as to its structure and operation together with the additional objects and advantages thereof are

best understood through the following description of the preferred embodiment of the present invention when read in conjunction with the accompanying drawings wherein:

Figure 1 shows a top view of a cross-section of a double-pane window with parallel strips of solar cells;

Figure 2 shows a frontal view of a cross-section of a double-pane window with parallel strips of solar cells;

Figure 3 shows the spectral response versus photon energy for a typical solar cell and a violet-responsive solar cell;

Figure 4 shows the transmissivity versus wavelength for a dichronic mirror;

Figure 5 shows an electrical assembly for a double-pane window with solar cells connected in series to increase voltage and in parallel to increase current;

Figure 6 shows a top view of an illumination sensor using a shade between parallel photocells;

Figure 7 shows a top view of an illumination sensor with angled photocells;

Figure 8 shows a motion control algorithm for the parallel strips of solar cells;

Figure 9 shows a semiconductor chip; and

Figure 10 shows a binary arithmetic calculator for calculating the tracking angle of the solar cells.

Description of the Preferred Embodiments

While the invention has been shown and described with reference to a particular embodiment thereof, it will be understood to those skilled in the art, that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

Figure 1 shows a top view of a cross-section of a double-pane window **100** which has exterior pane **101** and interior pane **102**. Double-pane window **100** could equally be called a dual-pane window. Exterior pane **101** and interior pane **102** are preferably flat panes and preferably made of glass. However, exterior pane **101** and interior pane **102** could be comprised of other materials, such as polycarbonate or acrylic. Exterior pane **101** and interior pane **102** are each parallel to the X-Z vertical plane shown in Figure 1. The X and Y axes in Figure 1 are in the horizontal plane, with the Y axis pointing from exterior pane **101** towards interior pane **102** of double-pane window **100**. In Figure 1, the Z axis is preferably pointing in the vertically-upwards direction.

Double-pane window **100** is preferably sealed against contaminants such as dust, dirt, and debris by seal **151** which runs along the outer perimeter of double-pane window **100**. In conjunction with seal **151**, spacer **150** also runs along the outer perimeter of double-pane window **100** to keep exterior pane **101** and interior pane **102** uniformly spaced. Seal **151** and spacer **150** preferably have the same thermal coefficient of expansion so that during diurnal and seasonal temperature changes, the seal is maintained. A typical material for seal **151** and spacer **150** is aluminum or an aluminum alloy. A thin elastomeric coating on seal **151** and spacer **150**, such as polytetrafluoroethylene, may be used to augment the sealing.

In between exterior pane **101** and interior pane **102** are a plurality of solar cells. In Figure 1, solar cells **120** and **121** are shown. Solar cell **120** rotates about the Z axis by being fixedly attached to rotating pivot shaft **110**. Similarly, solar cell **121** rotates about the Z axis by being fixedly attached to rotating pivot shaft **111**. Both solar cells **120** and **121** make the same angle **140** about the Z axis to receive sunlight **130**, meaning that the plurality of solar cells rotate in unison in double pane window **100**. Angle **140** is measured from the positive X axis. Angle **140** has a positive value when counterclockwise of the positive X axis, and a negative value when measured clockwise of the positive X axis, as shown in Figure 1.

Frontal view Figure 2 shows additional structure of double-pane window **100**. Pivot shafts **110** and **111** extend between spacers **152** and **153**. Spacers **152** and **153**

serve the same function as spacer **150** of Figure 1, which is to keep exterior pane **101** and interior pane **102** uniformly spaced.

Fixedly attached to pivot shaft **110** is gear **202**, and fixedly attached to pivot shaft **111** is gear **204**. Intermediate to gear **202** and gear **204** is pinion **203**. Pinion **203** rotates about shaft **222**, which is affixed to spacer **152**. Drive gear **201** is turned by drive shaft **221**, and drive shaft **221** is turned by motor **210**. Motor **210**, drive shaft **221**, drive gear **201**, gear **202**, pinion **203**, and gear **204** comprise a power train for rotating solar cells **120** and **121** in Figure 2. Drive gear **201**, gear **202**, pinion **203**, and gear **204** all have the same gear tooth systems, so that the teeth of adjacent gears mesh. The same gear tooth systems means that the gear teeth have the same pressure angle, same diametral pitch (ratio of the number of gear teeth and the pitch diameter of the gear), and overall similar general shape, otherwise the teeth of adjacent gears would not mesh and the power train would not operate. Drive gear **201**, gear **202**, pinion **203**, and gear **204** are preferably spur gears, but could alternately be helical gears. Due to the light loading to rotate solar cells **120** and **121**, drive gear **201**, gear **202**, pinion **203**, and gear **204** are preferably made of the polymer called DELRIN. However, drive gear **201**, gear **202**, pinion **203**, and gear **204** could also be made of other polymers such as NYLON or metals such as bronze, aluminum, titanium, or steel. Drive gear **201** is preferably fixedly held in place on drive shaft **221** via a set screw which is screwed against a flat on drive shaft **221**. Similarly, gears **202** and **204** are fixedly held in place via set screws which are screwed against flats on pivot shafts **110** and **111**, respectively. Pinion **203** preferably rotates freely about

static shaft **222**. Alternately, shaft **222** may freely rotate and pinion **203** is held in place on shaft **222** via a set screw which is screwed against a flat on shaft **222**.

Gears **202** and **204** have the same gear pitch-diameter. Pinion **203** need not have the same pitch-diameter as gears **202** and **204**; however, should additional pinions be placed between additional gears in support of additional solar cells, all pinions will have the same pinion pitch-diameter and all gears will have the same gear pitch-diameter, in order that all solar cells track the sun in parallel. If N gears are used in double-pane window **100**, then N-1 pinions are required. Drive gear **201** may have a smaller pitch diameter than gears **202** and **204**, in order to provide more leverage for turning solar cells **120** and **121**, thus allowing a smaller motor **210** to be used. Motor **210** could rotate pivot shaft **111** directly, without the use of drive gear **201**, but this would require a larger motor than if drive gear **201** is employed and drive gear **201** has a smaller pitch diameter than gears **202** and **204**.

Motor **210** is controlled by microprocessor **212**. Motor **210** is preferably a stepper motor. However, motor **210** could also be a gear motor. Microprocessor **212** sends instructions to motor **210** via motion control amplifier **211**, which amplifies the low level signals from the microprocessor into the current and voltage to rotate motor **210**.

Microprocessor **212** preferably receives the rotational position of a pivot shaft via position sensor **215** and position sensor monitor **214**. Position sensor **215** is preferably a digital encoder, and position sensor monitor **214** is preferably a digital encoder sensor.

However, position sensor **215** could alternately be a rotary potentiometer and position sensor monitor **214** an analog to digital converter. In Figure 2, position sensor **215** is fixedly mounted on pivot shaft **111**; however, position sensor **215** could equally be fixedly mounted on pivot shaft **110**. This way, microprocessor **212** can controllably rotate solar cells **120** and **121** up to ± 90 degrees. Solar cells **120** and **121** are not rotated more than this, so that the electrical wiring in double-pane window **100** is not multiply twisted and eventually broken. Solar cells **120** and **121** are not rotated more than ± 90 degrees, where zero degrees means that the solar cells are parallel to the X-Y plane and are parallel to exterior pane **101** and interior pane **102**, and +90 or -90 degrees means that the solar cells are perpendicular to the X-Y plane and thus are perpendicular to exterior pane **101** and interior pane **102**.

Microprocessor **212** also receives illumination input from position sensor **230** via wire **231**. Illumination sensor **230** provides feedback to microprocessor **212** as to whether solar cells **120** and **121** are best aligned with the incoming solar radiation. If the solar cells are not best aligned with the incoming solar radiation, microprocessor **212** can cause the solar cells to be rotated clockwise or counterclockwise until such best alignment is obtained.

Microprocessor **212** can also read from memory **213**. Memory **213** has information, such as the daily time of sunup and sundown in 24-hour time, and the number 15 which is used to compensate for the apparent motion of the sun. Our sun appears to move 360 degrees in 24 hours, which translates into 15 degrees per hour (360

degrees divided by 24 hours). Thus, microprocessor **212** needs to rotate solar cells **120** and **121** an average of 15 degrees per hour, during daylight hours. The time is provided to microprocessor is provided by 24-hour clock **217**. Clock **217** gives time in hours and the decimal fraction thereof. For example, if the time is 1:15 pm, clock **217** would give the time as 13.25 hours. Memory **213** also has information regarding sunup and sundown during the year, in 24-hour time, so that solar cells **120** and **121** can remain perpendicular to exterior pane **101** and interior pane **102**, thus allowing viewing out the window when the production of electricity is not possible.

Memory **213** also has the azimuth of the direction which double-pane window **100** is facing. For example, if double-pane window is facing due south, the value of the azimuth stored in memory **213** is 180 degrees.

Memory **213** is preferably a semiconductor chip. Memory **213** may be a PROM (programmable read only memory), EPROM (erasable, programmable read only memory), EEPROM (electrically erasable, programmable read only memory), or RAM (random access memory).

Thus, double-pane window **100** is capable of generating electricity while generally allowing light to enter a building. It is only during the period when solar cells **120** and **121** are parallel to exterior pane **101** and interior pane **102**, that viewing would be most encumbered. At other times, values of Angle_140 other than zero allows light to

illuminate the interior of the building and permits the occupant of that building to look outside, while solar-generated electricity is produced via light **130**.

The electricity generating surfaces of solar cells **120** and **121** can have special spectral-response properties, as depicted in Figure 3. Figure 3 shows plots of spectral-response **302** versus photon energy in electron volts **301** for a typical n-p Silicon solar cell **310** and a violet-responsive solar cell **311**. The active surface of typical solar cell **310** in Figure 3, has a depth of 0.4 micrometers and a surface doping of 5*10E19 per cubic centimeter. The notation 10E19 represents 10 to the 19^{th} power. However, the active surface of violet-responsive solar cell **311** has a shallower depth of 0.2 micrometers and an order of magnitude lower surface doping of 5*10E18 per cubic centimeter. This shallower depth and lower surface doping gives violet-responsive solar cell **311** a much higher spectral response in the green, blue, and violet range, photon energy greater than 2.1 electron volts, than typical solar cell **310**.

Violet-responsive solar cell **311** is well suited for use in double-pane window **100**, if an optional dichronic coating is applied to exterior pane **101**. A dicronic mirror reflects light of certain wavelengths and transmits light of other wavelengths, as depicted in Figure 4. In Figure 4, the transmission factor **402** of a particular dichronic mirror coating **411** is graphed versus wavelength **401**. This dichronic mirror coating is available from Nikon, at microscopyu.com. In Figure 4, the transmission factor **402** of 1.0 means 100%. The wavelength **401** is in nanometers. In Figure 4, the reflectivity is equal to [1 – transmissivity]. Thus, in Figure 4, the dichronic mirror coating **411** reflects light shorter

than 450 nanometers and longer than 680 nanometers. However, between 450 and 650 nanometers, dichronic mirror coating **411** transmits approximately 90% of the incoming light.

Using the dichronic coating **411** on exterior pane **101** would tend to block damaging ultraviolet radiation while permitting visible light to pass through in order to impinge upon the active surfaces of solar cells **120** and **121**, or for viewing by office occupants. Dichronic coating **411** is preferably on the inside surface of exterior pane **101**, so that it is protected from outside elements and occasional window cleaning. However, dichronic coating **411** could be on the outside surface of exterior pane **101**. Figure 4 shows that light of a wavelength longer than 450 nm, which represents an energy lower than 2.76 electron volts, is transmitted by diachronic coating **411**. Violet-responsive solar cell **411** converts solar energy into DC electricity in this region less than 2.76 electron volts, per Figure 3.

Table 1 shows the ranges of wavelengths of visible light, in nanometers, and the electron volt energy, thus allows the comparison of Figures 3 and 4. The electron volt energy is calculated by multiplying Planks constant, 4.136*10E-15 electron-volt-seconds by the speed of light 2.998*10E8 meters/second, and then dividing by the wavelength, as shown in the right-most column of Table 1.

Table 1. Wavelengths and Electron Volts of Visible Light

Color	Range of Wavelength in nanometers	Range of Electron Volts
Violet	400 – 424 nm	3.1 – 2.92
Blue	424 – 491 nm	2.92 – 2.53
Green	491 – 575 nm	2.53 – 2.16
Yellow	575 – 585 nm	2.16 – 2.12
Orange	585 – 647 nm	2.12 – 1.92
Red	647 – 700 nm	1.92 – 1.77

The dichronic coating in Figure 4 is the commercially available Nikon V-1A filter, from microscopyu.com, which reflects wavelengths of light shorter than 450 nm and transmits wavelengths of light from 450 nm to approximately 680 nm, which includes blue, green, yellow, orange, and red wavelengths. Infrared wavelengths greater than 700 nm are also reflected. Thus, the dichronic mirror coating in the Nikon V-1A filter transmits most of the visible light spectrum, while reflecting back out of the window the violet and short-wavelength-blue light.

Figure 5 shows an electrical assembly **500** for the conversion of direct current (DC) power from a plurality of solar cells **520**, **521**, **522**, and **523** into alternating current (AC) power. Solar cells **520**, **521**, **522**, and **523** generate DC current and voltage in double-pane window **100**. Solar cells **520** and **521** are connected as a subgroup in series, by conductor **503**, to increase DC voltage. Likewise, solar cells **522** and **523** are connected as a subgroup in series, by conductor **504**, to increase DC voltage. It is

preferred that all subgroups in double-pane window **100** have the same number of component solar cells, so that each subgroup has the same DC voltage rating.

The solar cell subgroups consisting of solar cells **520** and **521**, as well as **522** and **523**, are connected in parallel via conductors **501** and **502**, to increase the DC current. Conductors **501**, **502**, **503**, and **504** are preferably wires made of copper, but could be made of other conductive materials, such as aluminum or gold.

AC converter **510** converts the DC current and voltage from solar cells for assembly **500**, into AC current and voltage which would then be fed into the AC power grid of the building via conductors **511**. The AC current and voltage output of DC-to-AC converter **511** would preferably vary at a frequency of 60 Hertz (60 times a second) in the United States and preferably vary at a frequency of 50 Hertz in Europe. If the AC current and voltage output of DC-to-AC converter **511** is being superimposed with purchased AC power from a utility, the phase of the AC current and voltage from DC-to-AC converter **511** will have to match the phase of the AC current and voltage from the utility. In this manner, the solar generated DC electricity from window **100** is converted to usable AC electricity while window **100** still provides interior illumination and a view of the outside world.

Figures 6 and 7 show detail of illumination sensor **230** of Figure 2. In Figure 6, illumination sensor **600** has two photocells **601** and **603**. Both photocells **601** and **603** are oriented in parallel. In between photocells **601** and **603** is shade **602**. The output of

photocells **601** and **602** go to differential amplifier **604**. If one of the photocells is shaded, meaning that the solar cells **120** and **121** of Figure 2 are not pointed directly at the sun, the output of differential amplifier will indicate this to microprocessor **212**. Then microprocessor **212** can correct the alignment of the solar cells relative to the sun.

Similarly, in Figure 7, illumination sensor **700** has two photocells **701** and **703**. Rather than being oriented in parallel as in Figure 6, photocells **701** and **703** are oriented in at an angle to one another. The output of photocells **701** and **702** go to differential amplifier **704**. If one of the photocells more perpendicular to the sun than the other, meaning that the solar cells **120** and **121** of Figure 2 are not pointed directly at the sun, the output of differential amplifier will indicate this to microprocessor **212**. Then microprocessor **212** can correct the alignment of the solar cells relative to the sun.

Flowchart **800** describes the motion control algorithm for double-pane window **100**. This algorithm is stored in memory **213** and executed by microprocessor **212**. Flowchart **800** begins at stem **802** and flows to step **804**, where microprocessor **212** gets the sunup time, the sundown time, and the azimuth of double-pane window **100** from memory **213**. The process then flows from step **804** to step **806**, where microprocessor **212** gets the 24-hour time T from 24-hour clock **217**. The process flows from step **806** to decision step **808**, where the determination is made whether the 24-hour time T falls during daylight, i.e., between sunup and sundown. If the answer is no in decision step **808**, the process flows to step **810**, where ANGLE is set to 90 degrees. The process then

flows from step **810** to step **818**, where microprocessor **212** commands that motor **210** rotates solar cells **120** and **121** of Figures 1 and 2 in a generally counterclockwise direction until the angle of the solar cells ANGLE_140 is equal to the value of ANGLE determined in step **810**. This places the solar cells in double-pane window **100** perpendicular to the panes of glass and allows external viewing. Alternately, in step **810**, ANGLE could be set to 0 degrees and viewing into the double-pane window is blocked for privacy reasons between sundown and sunup. Regardless of whether ANGLE is 90 degrees for viewing or 0 degrees for privacy in step **810**, the activity in step **818** is called "parking" the solar cells.

If the answer is yes in decision step **808**, the process flows to step **812**, where ANGLE is calculated as ANGLE = Azimuth – 15*T. This equation is derived from (eqn.1):

$$\text{ANGLE} = 90 - 15\ \text{deg/hr} * [\ T - 6\ \text{hours} + (180 - \text{Azimuth})/15\ ] \qquad \text{(eqn.1)}$$

In (eqn.1), T is the 24-hour time and is obtained from 24-hour clock **217** in Figure 2. 15 degrees/hour is the apparent angular motion of the sun. When double-pane window **100** is facing due South in Figure 1, the Y axis is facing due North and the X axis is facing due East. Then, the azimuth of double-pane window **100** is 180 degrees. (Eqn.1) is designed so that the solar cells will face due East at 6.0 hours (6am), ANGLE_140 = 90 degrees; due South at 12.0 hours (noon), ANGLE_140 = 0 degrees; and due West at 18.0 hours (6pm), ANGLE_140 = -90 degrees.

Via the actual azimuth of the window, the term (180 – azimuth)/15 takes into account the time deviation of the double-pane window when it is not facing due South. Simplifying (eqn.1) results in (eqn.2), and it is (eqn.2) which is shown in step **812** of Figure 8.

$$\text{ANGLE} = \text{Azimuth} - 15*T \qquad \text{(eqn.2)}$$

The process then flows from step **812** to decision step **814**, where a check is made whether -90 degrees < ANGLE < 90 degrees. Step **814** is designed to keep the solar cells from seeking sunlight from behind the window and thus, from inside the building. If the result of decision step is no, then the process flows to step **810**. However, if the result of decision step **814** is yes, the process flows to step **816**, where microprocessor **212** commands that motor **210** rotate solar cells **120** and **121** of Figure 1 in a generally clockwise direction until the angle of the solar cells ANGLE_140 is equal to the value of ANGLE calculated in step **812**. The activity in step **816** is called "tracking" the solar cells. Step **816** may include a pause time of five to fifteen minutes, as it is not necessary for microprocessor **212** to activate motor **210** to track the apparent motion of the sun.

In Figure 8, and the explanation thereof, solar cells **120** and **121** are rotated alternately in a clockwise or a counterclockwise direction. Furthermore, solar cells **120** and **121** are never angled outside of the region -90 degrees ≤ ANGLE ≤ 90 degrees.

Thus, solar cells **120** and **121** never break their electrical wiring by twisting it multiple times in the same direction.

Memory **213** is preferably semiconductor chip **900**, as shown in Figure 9. Semiconductor chip **900** stores the algorithm in Figure 8, as well as a table of sunup and sundown times for each day of the year, and the azimuth of the installed window **100**. The exterior of chip **900** shows a typically square or rectangular body **901** with a plurality of electrical connectors **902** along the perimeter of body **901**. There is typically an alignment dot **903** at one corner of chip **900** to assist with the proper alignment of chip **900** on a printed circuit card. Within body **901**, chip **900** consists of a number of interconnected electrical elements, such as transistors, resistors, and diodes. These interconnected electrical elements are fabricated on a single chip of silicon crystal, or other semiconductor material such as gallium arsenide (GaAs) or nitrided silicon, by use of photolithography. One complete layering-sequence in the photolithography process is to deposit a layer of material on the chip, coat it with photoresist, etch away the photoresist where the deposited material is not desired, remove the undesirable deposited material which is no longer protected by the photoresist, and then remove the photoresist where the deposited material is desired. By many such photolithography layering-sequences, very-large-scale integration (VLSI) can result in tens of thousands of electrical elements on a single chip. Ultra-large-scale integration (ULSI) can result in a hundred thousand electrical elements on a single chip.

Figure 10 shows binary arithmetic calculator **1000** for the simplified calculation of ANGLE in step **812** of Figure 8. This simplification eliminates the need for digital multiplication by microprocessor **212**, which may reduce the cost of microprocessor **212** and hence the double-pane window **100**. (Eqn.2) is rewritten as (eqn.3), where -15*T is now calculated as T-16*T. The azimuth, which double-pane window **100** is facing, is stored in memory **213** in binary form. Binary form is equally known as base-2. For example, an azimuth of 135 degrees, representing double-pane window **100** facing the south-east, is 207 in base-8 and 10000111 in base-2. Since the azimuth of an installed window typically does not change, the binary value of azimuth typically needs to be calculated only once, when double-pane window **100** is first installed. Time T generated by clock **217** as a binary number. Then, in register **1010** of microprocessor **212**, time T is bit-shifted by the left by four bits, which is the same as multiplying time T by 1000[base-2], which is equal to 16[base-10]. Finally, accumulator **1020** adds azimuth, then adds time T, then subtracts 16*T from the output of register **1010**, to yield (eqn.3). (Eqn.3) is identical to (eqn.2); however, (eqn.3) does not require digital multiplication. (Eqn.3) only requires a simple bit-shift by four bits to the left, addition, and subtraction, to calculate ANGLE in step **812** of Figure 8.

$$\text{ANGLE} = \text{Azimuth} + T - 16*T \qquad \text{(eqn.3)}$$

In Figure 1, the Z axis is preferably pointing in the vertically-upwards direction. This is especially desired for a south-facing double-pane window **100**. However, for an east-facing or a west-facing double-pane window **100**, the alternate embodiment of

having the X axis parallel to the vertical direction may be desirable. For an east-facing window, the X axis would be pointing in the vertically downwards direction. For a west-facing window, the X axis would be pointing in the vertically upwards direction. Figure 8 would not need to be altered. The azimuth of the east-facing window is 90 degrees, and Figure 8 calculates ANGLE in step **812** as 0 degrees at 6am, or T=6.00 hours, meaning that the solar cells are parallel to the east-facing panes of glass at that time, as generally desired. Similarly, the azimuth of the west-facing window is 270 degrees, and Figure 8 calculates ANGLE in step **812** as 0 degrees at 6pm, or T=18.00 hours, meaning that the solar cells are parallel to the west-facing panes of glass at that time, as generally desired. This alternate embodiment would be of increasing value for double-pane windows **100** installed near the equator of the Earth. For both the east and west-facing double-pane windows **100** in this alternate embodiment, the Z axis of Figures 1 and 2 would point generally in the northern direction so that the solar cells track in the clockwise direction to follow the apparent motion of the sun.

While the invention has been shown and described with reference to a particular embodiment thereof, it will be understood to those skilled in the art, that various changes in form and details may be made therein without departing from the spirit and scope of the invention. For example, double-pane window **100** is described in the traditional sense as being in a vertical plane, which means to be along the side of a building. However, double-pane window **100** could equally be installed at an angle to the vertical, such as in a skylight.